Study on The Intelligence Control System of Artificial Cooing Source in Architecture

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Abstract: To overcome the shortcoming of constant temperature and humidity in artificial cooling source control system, a dynamic indoor temperature control strategy was put forward under health and thermal comfortable principles. With a lump human model , the reliability of the strategy was verified by Matlab simulation. The strategies were realized with a S7-300 controller in an artificial climate lab . Using Fuzzy-PID arithmetic and forward-feed and feedback control method, the real time control was achieved. In the system, MPI channel was used to communicate between PLC and PC, and WINCC was used for the man-machine conversation.

Key words： cooling source; dynamical thermal comfort; PLC; artificial microclimate lab

1 INTRODUCTION

Energy problem has became a choke point of social development .However, 30~40 percentage energy consumed in architecture. To maintain a comfortable indoor microclimate, artificial cooling source used widely in building .From some statistic ,compressor and fan consumed about 85 percentage energy of cooling system. Thus, minimizing the energy consumption in cooling source and enhancing the thermal comfortable has significant meaning.

Traditionally , the cooling source control strategy is proposed on the basis of the constant indoor temperature. Actually, changing the indoor temperature moderately will benefit to the health. Because people can secure his own comfort through physiological adjustment which can improve the immunity[1].Some experiment done for the dynamical thermal comfort, conclusion were drawn: the comfort temperature is related to the outdoor temperature and so to the climate. There is no universal comfort temperature. Each community must have its own perception of the thermal comfort.. Commonly, a relationship between Optimum indoor temperature and outdoor temperature was put forward as[2] :(k and b are constant value)

$$t_i = kt_e + b \tag{1}$$

There are many different correlations between t_n against t_e , The one given by Kwok Wai Horace Mui was:

$$t_n = 18.303 + 0.158t_e \tag{2}$$

the other for Humphreys was :

$$t_n = 23.9 + 29.5(t_e - 22) \times \exp^{-((t_e-22)/(24\times\sqrt{2}))^2} \tag{3}$$

the other put forward by Auliciems was :

$$t_n = 9.22 + 0.14t_e + 0.48t_i \tag{4}$$

In china ,the dynamic thermal comfort theory was focus on the terminal devices of HV&AC system. The strategy of changing the indoor temperature put forward ,[3],but it is not realized in practice.

2 THEROY OF DYNAMICAL THERM- AL COMFORT ABOUT HUMAN

In the unsteady state ,the energy balance between people and environment is[4]:

$$S = M - W - R - C - E - K = \rho c V \partial t / \partial \tau \quad (4)$$

$$R = \varepsilon \sigma A_{Du} f_{eff} f_{clr} F_{clr} (T_r^4 - T_s^4) \quad (5)$$

$$A_{Du} = 0.208 + 0.006789 \times l^{0.725} \times G^{0.425} \quad (6)$$

$$F_{clr} = 1 \big/ \left[1 + 0.155 \times 5.2 I_{clo}\right] \quad (7)$$

$$f_{clr} = 1 + 0.155 I_{clo} \quad (8)$$

$$C = h_c A_{Du} f_{clo} (t_a - t_k) \quad (9)$$

To simplify the model, h_r ,a equivalent convective coefficient ,is used to calculated the R.From the literature, when the air temperature is in the 5～50℃，h_r will vary between 3.8～5.1（w/m^2.k）

$$R + C = f_{clo} A_{Du} (\alpha_r + \alpha_c)(t_k - t_a) \quad (10)$$

$$E = E_{res} + E_{dif} + E_{sw} \quad (11)$$

$$E_{res} = 0.0014M(34 - t_a) + 0.0173M(5.867 - p_a) \quad (12)$$

$$E_{dif} = 3.05(0.255 t_s - 3.335 - p_a) \quad (13)$$

$$E_{sw} = 0.42(M - W - 58.2) \quad (14)$$

$$\alpha_c = 12.1 u^{0.25} \quad (15)$$

$$t_k = 25.8 + 0.267 t_o \quad (16)$$

$$t_o = \frac{\alpha_r t_r + \alpha_c t_a}{\alpha_r + \alpha_c} \quad (17)$$

For air conditioning building, t_o can simplified as

$$t_o = t_a = t_r \quad (18)$$

Using the two node model , The average temperature of human can .expressed as :

$$t = (1 - c) t_k + c t_{oc} \quad (19)$$

If c=0.8, it denotes thermal comfort for people，for c=0.8～0.9,a sweat state occurred ，while, c＜0.67,people will feel somewhat cold[4].

Keeping other indoor micro-climate parameters constant , the correlation between velocity and air temperature can be drawn as :

$$\frac{u_1}{u_2} = \frac{(25.8 - 0.733 t_{a2})^2}{(25.8 - 0.733 t_{a1})^2} \quad (20)$$

.Experiment shown the thermal comfort can be improved when the air flow velocity increasedt.[5] Furthermore, changing the indoor temperature periodic will be beneficial to health.. Considering the energy saving , enhancing the indoor temperature as the outdoor temperature increased will reduce the cooling load. Therefore, in the paper, the indoor temperature set as the same change periodic as outdoor temperature.

$$t_o = t_{op} + A\cos(15\tau - 225) \quad (21)$$

To define the t_{op} and the A, the follows literature were referenced:

1:C.H.Sprague do the research on in the influence of temperature fluctuating on the human, the conclusion was drawn as[5]

$$A_t^2 \times (c.p.h) \le 4.6 \text{ ℃/h} \quad (22)$$

It means people will feel cold when the temperature drop gradient more than 0.004℃/s, and feel hot when raise gradient more than 0.001℃/s

2:The research done by Rohles indicated. when RH is 50%，with certain air velocity, the upper comfort temperature can reach to 29.4℃。when the velocity below 0.6m/s, increase the velocity 0.1m/s every time equal the indoor air temperature drop 0.3℃。under the same air velocity ,the air temperature can increase 1.5℃。

3: In china ,the indoor temperature of air conditioning room was set among 24~28℃ in design handbook.

Considering the factor mentioned above , the indoor air temperature set as follows in summer day.:

$$t_a = 26.5 + 2.5\cos(15\tau - 225) \quad (23)$$

Combined the formulas (1)~(23), the lump thermal model of human can be expressed as

$$\begin{cases} 244300\dfrac{dt}{d\tau} = 621 + 3.86t_a - 18.5t + \\ \dfrac{5313.2 + 35.9t_a - 179.5t}{28.5 - 0.733t_a} \\ v = 0.25 \qquad \tau = 0 \\ t_a = 24.7 \qquad \tau = 0 \\ t = 37 \qquad \tau = 0 \end{cases} \tag{24}$$

c= 3.48kJ/kg.℃，G= 70kg，L=1.7m, M =116W。

p_a=1.55kpa (As air temperature vary from 26℃to29 ℃，the vapor pressure changed only about 0.2kpa) With the matlab program ，the simulation result shown in Fig.1。Under the dynamical control strategy, the average human temperature changed as: $|t| \le 0.25$ ℃， which meet the human body's self-regulation range: $|t| \in \{0.4, 1.1\}$ []。 In other word , the correct of the control strategy was verified in the theory.

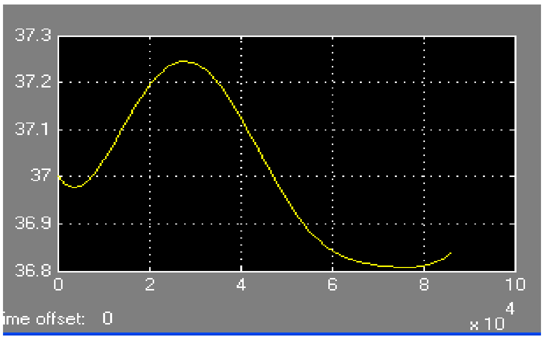

Fig.1 the graph of human temperature changed under dynamical indoor air temperature

3 EXPERIMENT ON THE INTELLIGENCE CONTROL OF ARTIFICIAL COOLING SOURCE BASED ON THE DYNAMICAL THERMAL COMFORT

To realize the real time changing indoor air temperature , a control system was set up for an artificial climate lab built in our lab.

3.1 Configuration of Artificial Climate Lab

The walls of lab was made up of 100mm polystyrene boards. For the position of vent can change flexible and the perforated pane , clap board can be moved away ,the lab has multi-function. For example , diversiform air flow style can achieved.

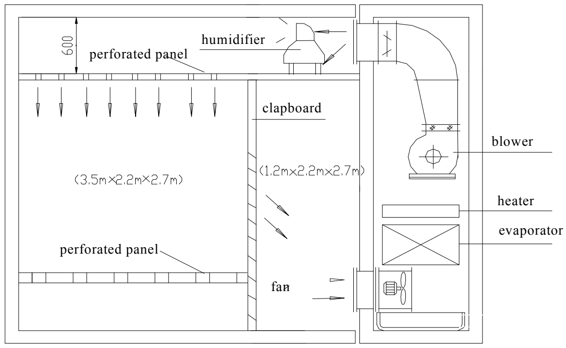

Fig.2 The configuration of artificial climate lab

3.2 The Hardware of Control System

The hardware system includes SIMENSE s7-300 center controller and the AI, AO, DI, DO, ps modules etc. AI module connected with the velocity ,temperature, humidity transmitters and the thermocouple ,manometer etc; AO module connected with the frequency conversion(for compressor and blowers) and thyristor(for heater) ; DI module connected the manual operation button and the annunciator; while ,the DO module transfer PLC signal to the relays and control the equipments. PLC joint with PC via the MPI card .The communication between them obey the Simense s7 protocol. By the RS232 COM ,the Touchkit that used as display connected with PC.

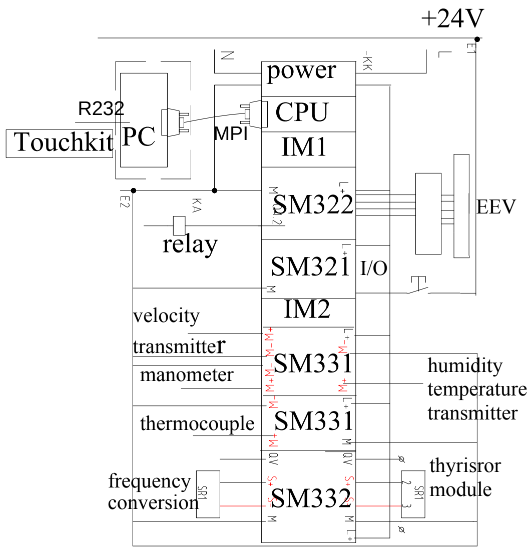

Fig.3 The hardware system

3.3 Software of control system

The control strategy shown in Fig.4.PLC program in

Fig.5. The transfer function of EEV is

$$W_e(s) = \frac{0.0462}{(34.7s+1)^4} \qquad (25)$$

Under the completely compensate principle[10] , the transfer function of forward feedback channel is:

$$W_{FF}(s) = -\frac{W_{blower}(s)}{W_{lab}(s)} \qquad (26)$$

$$W_{FF}(s) = -\frac{\frac{0.5905}{1+87s}e^{-110s}}{\frac{1.467}{3223s+1}e^{-109.6s}} \qquad (27)$$

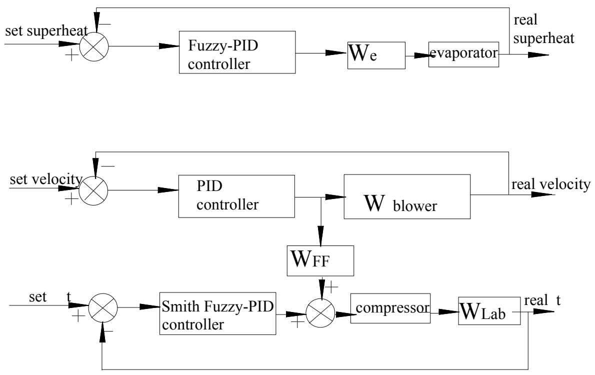

Fig.4 control strategy of indoor temperature

3.2.2 PLC program

With the LAD language, the PLC program is edited as follows. There are three organize blocks and 10 function blocks and 12 data blocks[6]

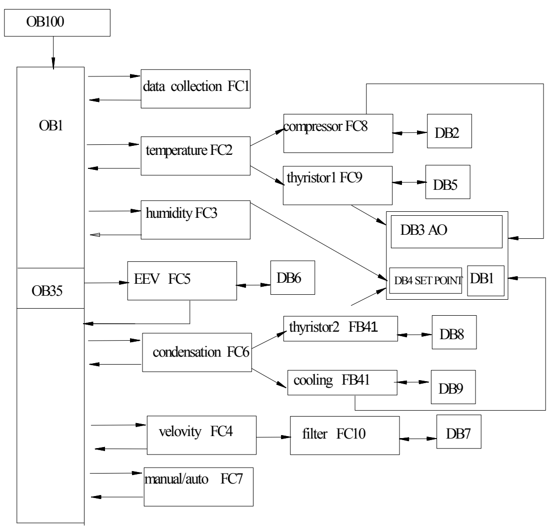

Fig.5 the structure of PLC program

3.2.3 Control algorithm

Obviously ,the transfer function of climate lab has the lag time. To realize the real time control, the smith fuzzy-PID is used[7]. The fuzzy illation system is based on Mamdani principle.

The input variables are temperature error (e)and the error change ratio(ec) ;The output is the k_pid(1 , k_pid(2) , k_pid(3) accordingly.

In the system ,Z, gaussmf, and trimf membership function are used.

The range of kp ,ki ,kd is [-3 3][-0.1 0.1[;：[-300 300] respectively .

The range of e and ec are [-1.6 1.6][-0.3 0.3];

The rules are edited on the function of kp ,ki ,kd in the PID controller . There are seven fuzzy subclass {PB,PM,PS,ZO,NS,NM,NB}adopted in the system, moreover, centroid method is used to defuzzification.

The kp(k), ki(k) and kd(k) in the controller are calculated as:

$$kp(k)=xi1\times kp0+k\_pid(1)\times xi11 \qquad (28)$$

$$ki(k)=xi2\times ki0+k\_pid(2)\times xi22 \qquad (29)$$

$$kd(k)=xi3\times kd0+k\_pid(3)\times xi33 \qquad (30)$$

kp0 ,ki0, kd0, are the initialization values. xi is the adjustive coefficient .After trial and error ,set the coefficient as :i3=1.0；xi11=1.0；xi22=0.1；xi33=0.0；kp0=20；kd0=1000； ki0=0.35.

Simulation result displayed in Fig.6(the black line symbol the common fuzzy-pid).Obviously ,when the smith control added , the system can respond timely.

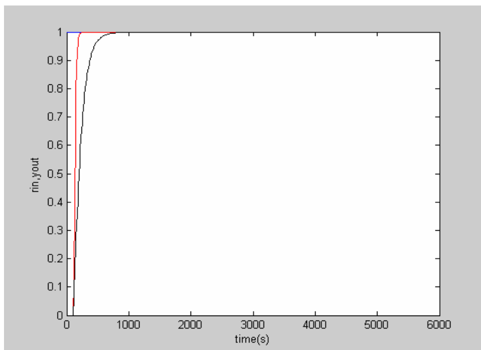

Fig.6 Simulation result of simth fuzzy-pid

4 RESULT

As the climate lab built in our laboratory ,it cannot really have the outdoor meteorologic boundary condition . Then ,the thyristor1 is used to simulate the change of thermal load. A regression equation for power of heater(y) and thyristor1 signal(x) can expressed as follows:

$$y = 3.95554 + \frac{3.9835}{(1+(\frac{x}{6.1792})^{4.60648})} \qquad (31)$$

Real time thermal load. was calculated under the these conditions:

1) outdoor temperature and solar radiation values are meteorologic parameters in July of Tianjin (Fig.7)

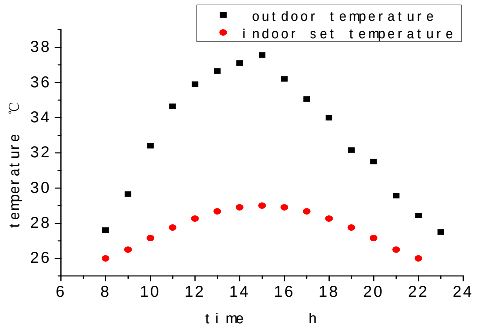

Fig.7 Outdoor and indoor temperatur

2)Assumed a 13.5m*5.4m*3.3m office is simulated which has two 6mm double glass window(2.4m*2.0m) with blue purdah , the exterior walls are south and west wall, $K_{wall} = 0.57$ w/m^2.℃, $K_{roof} = 0.79$ w/m^2.℃; 3)there are five people in the room ;4) the total power of lamps and equipment is 2200w.

With the composite control strategy, the real time indoor air temperature and the power of compressor were shown in Fig.8 and Fig.9.

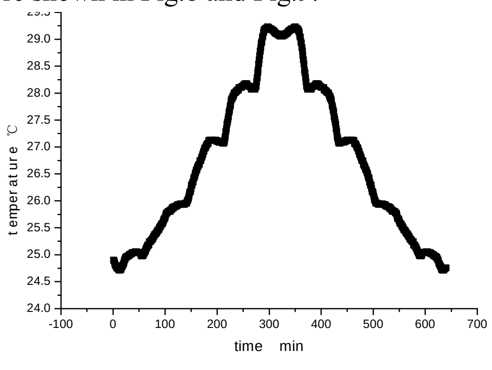

Fig.8 real time indoor temperature curve under the smith fuzzy-Pid control

Comparing with the constant indoor set temperature($t_i = 26$℃), 10.6% energy consumption will reduced. Certainly, if the blowers are not placed in the lab , the potential of energy saving will increase.

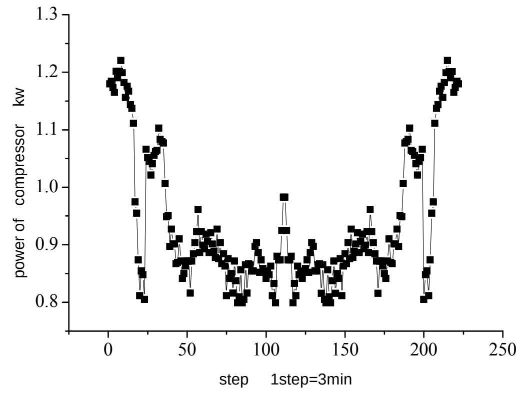

Fig.9 real time compressor power curve under the smith fuzzy-Pid control

5 CONCLUSION

1:The unsteady lump human model simulation result indicated: if the indoor temperature amplitude about 2.5℃,with the same fluctuant frequency as outdoor temperature's and the velocity varied between 0.25~0.65m/s, the average human temperature changed about 0.25℃，which meet the human body's self-regulation range. It will benefit to the human body.

2: Comparing with the constant indoor set temperature($t_i = 26$℃), 10.6% energy consumption will reduced under dynamical indoor temperature Certainly, if the blowers are not placed in the lab and the fresh air cooling load were calculated, the potential of energy saving will increase more.

3:SmIth fuzzy-pid control strategy can realize the real time control of cooling system.

4:For the complex of dynamical thermal comfort, there are many things to do in the future.

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NOMENCLATURE

t_i indoor temperature, ℃

t_e outdoor temperature, ℃

t_n netural temperature, ℃

S rate of heat storage , w/m^2

M metabolic heat production w/m^2

R radiant heat transfer rate

C convective heat transfer rate w/m^2

E respiratory trace heat loss, w/m^2

K conductive heat transfer rate , w/m^2

ρ density, kg/m^3

c specific heat capacity kJ/kg.k

V volume m^3

t average temperature of body

τ time , s

ε emissivity

σ Stefan-Boltzmann canatant

A_{Du} body surface area , m^2

f_{eff} effective skin area for radiant heat transfer , m^2

f_{clr} radiant area increased for cloth , m^2

f_{clo} emendatory factor of convective heat transfer rate cloth

F_{clr} emendatory factor of cloth to radiant heat transfer rate

T_s skin temperature of human, k

E_{res} heat transfer rate through respiration , w/m^2

E_{sw} heat transfer rate through sweat, w/m^2

E_{dif} heat transfer rate through diffusion, w/m^2

t_o operative temperature, ℃

t_a indoor air temperature, ℃

t_r mean radiant temperature, ℃

t_k temperature of skin layer, ℃

t_{oc} temperature of core node of human body, ℃

t_{op} optimium indoor average temperature , ℃

α_c convection coefficient, w/m^2.℃

u air velocity ,m/s

α_r equivalent radiant heat transfer coefficient, w/m^2. ℃

G weight of human body ,kg

L height of human body, m

p_a partial water vapor pressure, kpa

A_t - amplitude of temperature fluctuating, ℃

c.p.h - fluctuating frequency.

$W_{FF}(s)$ forward-feed transfer function

$W_{blower}(s)$ transfer function of blower

$W_{lab}(s)$ transfer function of microclimate lab

$W_e(s)$ transfer function of electronic expansion valv